Ecological significance of freshwater seeps along the western shore of the Leschenault Inlet estuary

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Abstract

The natural seepage lines of the Leschenault Peninsula are expressions of the topography and stratigraphy, which act as sink and conduits for discharging groundwater. The drainage of the aquifer follows the lowest point in the landscape, and continues for some time after winter rainfall has ceased. Freshwater seepage sites are important in the first instance for peripheral estuarine vegetation that exploit these zones of lower salinity in an area of otherwise saline high tidal flats. Secondly, freshwater sources in the hot dry summer environment may be exploited by avifauna, particularly as no permanent freshwater sources exist on the Peninsula.

Keywords: Leschenault Inlet, south-western Australia, estuary, freshwater seepage, peripheral vegetation.

Introduction

The Leschenault Peninsula separates the shallow saline water of a lagoon, the Leschenault Inlet, from the Indian Ocean, and consists of vegetated and mobile dunes. There are no streams or channels on the Peninsula, and drainage is internal. Winter rainfall recharges the groundwater system of the peninsula with a resultant rise in groundwater level. During the ensuing spring and early summer, the elevated water table discharges to the inlet and the ocean through freshwater seepage. This seepage forms important sites of mixing between freshwater and saline water which influences the occurrence and distribution of native shore vegetation, and combined with the natural setting and food resources of the Leschenault Inlet, provides important habitat for both permanent and migratory birds.

The objective of this paper is to describe the geomorphic, stratigraphic and hydrologic setting of the Leschenault Peninsula barrier dunes in their relationship to the western shore of the Leschenault Inlet estuary to explain the localised sites of freshwater seepage along this western shore, and to describe some of its ecological effects. The approach of this study was one of using landscape ecology which attempts to integrate data from a variety of disciplines (in this case geomorphology, stratigraphy, hydrology, vegetation, and avifauna) to provide an understanding of ecological processes and patterns. The value of such an approach is that it provides integrated multi-disciplinary information for management.

Regional setting

The Leschenault Peninsula is a linear barrier dune system, some 12 km long and 0.5-1.5 km wide (Fig 1), and is located along the south-western Australian coast in the Leschenault-Preston Coastal Sector (Searle & Semeniuk 1985; Semeniuk 1985). Geomorphologically, this coastal terrain is referred to the Quindalup Dunes, the system of white to cream coastal dune sands distributed along the Western Australian coast from Geographe Bay to Dongara (McArthur & Bettenay 1960; Semeniuk et al 1989). The study area has an annual rainfall of *ca* 880 mm, and an annual evaporation of *ca* 1980 mm (Anon 1975; Semeniuk & Meagher 1981a). Tides in this region are microtidal, with a maximum range of 0.9 m, and a prevailing range of 0.5m.

Stratigraphy of Leschenault Peninsula

The Leschenault Peninsula is comprised of up to 40 m of Holocene dune sand forming an extensive shore-parallel prism and referred to the Safety Bay Sand, which is mainly quartz and carbonate fine to medium sand of coastal aeolian origin (Semeniuk 1983). The Safety Bay Sand is underlain by a ribbon, some 6 m thick, of Leschenault Formation, an estuarine sedimentary unit composed of mud, shelly mud, muddy sand, and grey sand. This formation underlies and interfingers with the Safety Bay Sand on the eastern side of the barrier. Here, the stratigraphic relationship between the two formations is complex for the following reasons (Semeniuk 2000):

- the present shore face between the dune and the estuary is comprised of dune fingers (the fronts of parabolic dunes) extending into the muddy environments of the estuary, with muddy sediments accumulating between the dune promontories, generating a laterally alternating system of dune sand bodies overlying muddy sand sequences and mud sequences;
- the Leschenault Formation varies lithologically laterally and down-depth from muds to muddy sand to sand, with the various lithologies developed in lenses, ribbons and sheets, and interfingering; and
- the present contact between dune sand and the muddy sediment of the estuary along the eastern side of the Peninsula is situated at about the high tide mark, however, earlier in the Holocene, with sea-levels higher than at present (Semeniuk 1985), the contact locally could be up to 2 m or more above the present high tide level.

On the east side of the barrier, the Safety Bay Sand is fairly consistent in its lithology throughout its length and depth, while the Leschenault Formation is more variable, with mud, or muddy sand, or sand developed at the contact between it and the Safety Bay Sand, and the stratigraphic contact developed at the level of the present high water mark or higher. All of these factors have implications for

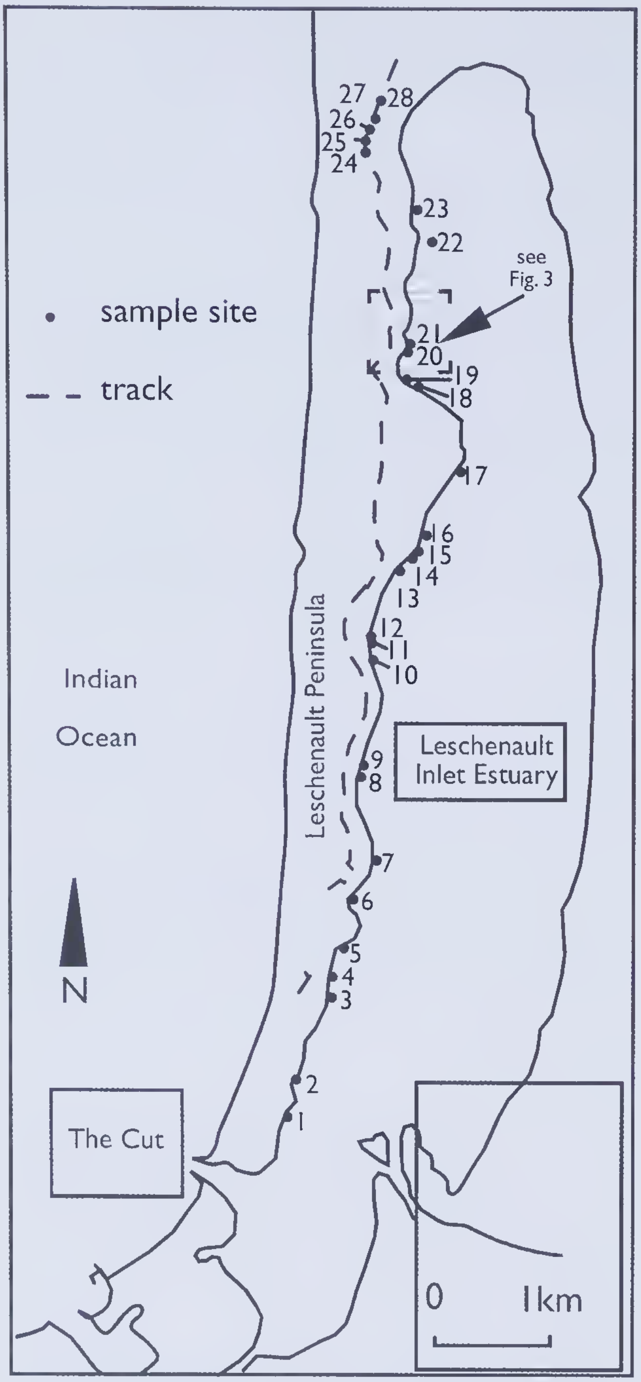

Figure 1. Location of sampling sites along eastern shore of the Leschenault Peninsula.

the hydrological dynamics along the Leschenault Peninsula eastern shore.

Hydrology

As a barrier dune complex, Leschenault Peninsula separates the marine waters of the Indian Ocean to the west from the marine to estuarine waters of Leschenault Inlet to the east (Fig 1). Under the Peninsula, within the Safety Bay Sand, there is a prism of freshwater, and a saline/freshwater interface descending steeply at depth on both the ocean and estuarine side of the barrier (Semeniuk & Meagher 1981b). In essence, this hydrological situation is an analogue of a freshwater lens in an oceanic island setting, where a core of freshwater is surrounded by marine water. The groundwater table under the Peninsula is not planar, but forms an asymmetrical low mound, rising up to 0.8 m above sea-level towards the ocean side of the Peninsula, and located *ca* 0.2 m above sea-level towards the inlet side of the Peninsula (Fig 2; after Semeniuk & Meagher 1981b).

Hydrologic dynamics

In response to seasonal rainfall, the water table under the barrier dune fluctuates vertically 0.3-0.5 m, locally raising the water table to 1 m above MSL (Semeniuk & Meagher 1981b). At times of maximum water table elevations, when there may be a 0.5-1.0 m hydraulic head difference between the freshwater water table and the surface of the marine/estuarine water bodies, there is freshwater discharge (expressed as surface seepage) into lowlands and into the adjoining tidal zones. On the eastern side of the Peninsula, where groundwater hydrodynamics are important to the subject matter of this paper, the water table generally slopes down to the estuary margin. Here there are three situations that determine the style and amount of freshwater discharge:

1. dunes are truncated by estuarine coastal erosion forming small sand cliffs 1-3 m high; winter-recharged groundwater stored in the barrier discharges into the inlet along this estuary shore;
2. large fingers of dune sand (encroaching parabolic dunes) extend into the estuary; a low mound of freshwater occurs under such fingers, and these form reservoirs to discharge locally into the Inlet environment; and
3. a shallowly buried sheet of mud slopes towards the estuary; this acts as an aquatard and water discharging vertically under a high winter hydraulic head is laterally diverted, and discharges along the estuary shore.

At times of low tides, the hydraulic head between the groundwater under the barrier dunes and the adjoining Inlet is relatively large, and the discharge outlined in the three situations above is exacerbated. Discharge along the estuarine shore-face during these times of low tide are best developed during the winter/summer transition, for the following reasons: 1. mean sea-level is falling from a winter high to a summer low (Semeniuk & Meagher 1981b); 2. winter watertable levels are at their maximum, and hence the hydraulic head differences between the freshwater aquifer and the estuary are most marked; and 3. this time generally is a period of equinoctial tides, further increasing the difference in the hydraulic head.

Methods

The identification of natural seepage lines from the Leschenault Peninsula into the Leschenault Inlet was undertaken using three environmental indicators:

1. landform/vegetation units; 2. salinity of surface water and groundwater; and 3. occurrence of avifauna.

A study of the landscape features of landform and vegetation was undertaken along the full length of the Peninsula as the first step to more narrowly define possible seepage points. Interpretation of dune morphology and vegetation units along the eastern shore of the Leschenault

Peninsula provided potential freshwater seepage sites for more detailed field investigation. Stereoscopic aerial photographic interpretation (SAPI) of the landform characteristics and associated vegetation units was undertaken to determine those landform elements most likely to be associated with freshwater seepage. Four major landform elements were investigated:

a) interdunal swales oriented perpendicular, and close to, the inlet edge;

b) sharp interdunal contact areas between converging dunes, close to, or at the inlet edge;

c) apical cusp (or "toe") of dunes close to, or at the inlet edge; and

d) localised elongate depressions, particularly those oriented perpendicular to the inlet edge.

A field survey was undertaken to ground-truth landform units identified by SAPI, to document vegetation, to collect surface and groundwater water samples, and to observe avifauna in relationship to any identified freshwater seepage. To identify and ground-truth potential seepage sites, a complete north-south traverse of the inlet/peninsula interface was undertaken, with selected sites revisited for observing avifauna and sampling for water. The ground-truthing of landform units was undertaken to verify that the units defined by SAPI were actual changes in topography and vegetation cover, and not an artifact of changes in aerial photographic tones.

Vegetation was surveyed to determine its relation to surrounding landforms, and particularly in relation to areas where the "wetness" of the estuarine environment continued up-slope beyond the intertidal range, indicating freshwater seepage. The survey of the vegetation was a broad identification of major units, rather than quantitative quadrat survey. The survey concentrated on the structural vegetation units of 'rushland' and 'sedgeland' along the land/estuary interface to identify areas of wetland vegetation type continuing beyond the inlet edge.

Once potential seepage points were identified using the landform and vegetation indicators, more detailed surface water and shallow groundwater sampling was undertaken. Twenty-eight such sites were identified (Fig 1). At each potential seepage site the vegetation was traced up-slope to the landward extreme of the "wetness", which was usually at the edge of higher relief dunes. The site of potential freshwater seepage represents areas of lower salinity within a context of a saline upper tidal flat. At each locality, a surface water or groundwater sample was collected. Where this interface was more than 100 m from the inlet edge (*i.e.* the "area of wetness" was extensive or linear perpendicular to the inlet edge between converging dunes), a second, or third water sample was collected closer to the inlet. Each water sample was collected from shallow groundwater or from surface water pools greater than 10 cm below the surface of the water, where possible, to account for any possible fresh water perched on top of potentially a more saline base water. Site 21 was revisited for mapping and water sampling in March 1997.

Observations on the avifauna were undertaken on two occasions following Storr (1991) and Johnstone & Storr (1998): firstly, during the initial traverse of the inlet/peninsula interface and water sampling, and on a second field visit to collect further water samples and to specifically observe bird behaviour in relation to the seepage areas in early summer. Birds were observed for potential usage of freshwater seepage along the entire length of the Peninsula, though effort was concentrated on areas already identified by the landform analysis as the main seepage sites. Field studies were carried out in spring and early summer after the majority of the year's rainfall had ceased, and maximum seepage of groundwater would be expected from the elevated groundwater levels on the Peninsula.

Water samples were determined for salt content in the field with a refractometer, and confirmed in the laboratory using an electrical salinometer.

Results

Broad seepage front

The length of the edge of the dune terrain of the Leschenault Peninsula generally abuts a narrow to broad high-tidal flat. Groundwater residing within the dune sand

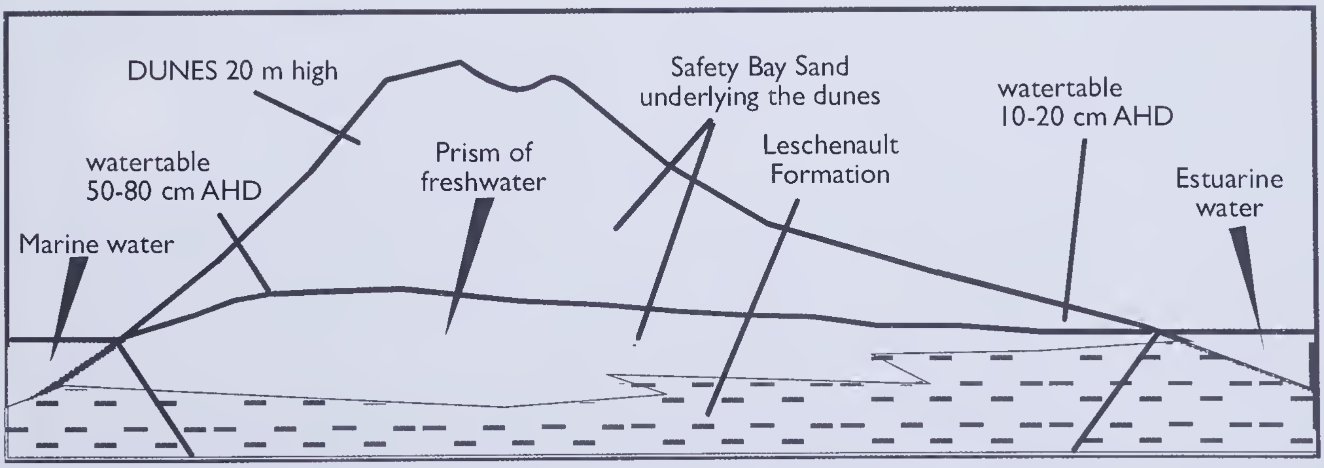

Figure 2. Idealised cross-section of the Leschenault Peninsula showing stratigraphic and hydrologic features (after Semeniuk & Meagher 1981b). Maps showing terrain, study sites, seepage sites, and salinity values of sampling sites around the dune projection of Site 21 in March 1997.

Table 1. Salinity of sampling sites 1 part per thousand = 1000 mg L^{-1}. Values are mean and number of samples (n).

Sampling Site	Total Dissolved Solids ‰	n
1	2.2*	4#
2	22.6	2
3	8.5	3
4	13.5	2
5	3.8+	2
6	1.4*	2
7	17.1	1
8	2.0*	4
9	17.6	2
10	3.8+	1
11	14.7	1
12	3.2+	2
13	17	1
14	2.95+	2
15	3.2+	2
16	20	1
17	3.2+	1
17	4.9+	1
19	4.9+	1
20	1.6*	2
21	0.4*	1
22	19	1
23	4.0+	1
24	10.5	1
25	1.6*	1
26	4.5+	1
27	3.2+	1
28	30	1

* < 3 000 mg/L^{-1}TDS

\+ 3 000 - 6,000 mg/L^{-1}TDS

\# One value deleted, as considered atypical.

is freshwater (Semeniuk & Meagher 1981), and that under the tidal flats is saline to hypersaline. Vegetation on the dunes comprises a mix of shallow to deep-rooted, phreatic and vadose freshwater dependent terrestrial vegetation, while that on the tidal flats comprises halophytes. The interface between the two vegetation systems is a ubiquitous shore-parallel seepage of freshwater. Across this interface, groundwater salinity changes in the direction from estuary to landward, from saline to brackish to fresh (Table 1; Fig 3). Hence, it is a zone of mixing of freshwater and saline water, and is inhabited by a fringe of *Juncus kraussii* closed rushland (*Juncetum kraussii* association of Cresswell & Bridgewater 1998), which is euryhaline in its habitat range).

Discrete seepage sites

In addition to the laterally extensive seepage front, there are numerous discrete seepage points where there is a more pronounced localised freshwater discharge into the saline tidal flats. Landscape analysis of landform and vegetation using aerial photographic interpretation identified 28 such seepage sites, mostly covered or surrounded by *Juncus kraussii* closed rushland. Twenty four of these seepage sites contained some open standing water (*i.e.* windows to the water table) at some part of their distribution, ranging from very small pools directly on the dry dune/wet zone interface (less than 1 m^2) to extensive ephemeral wetlands (over 500 m^2) occurring as shallow pools within the high-tidal flats along the inlet edge. A list of seepage sites and notes on the surrounding vegetation are presented in Tables 2 and 3.

Along the northern section of the Peninsula, the landform abutting the Inlet is mostly undulating plain, and the peripheral vegetation to the seepage sites is dominated by *Eucalyptus gomphocephala* open forest and *Melaleuca rhaphiophylla* low open forest with *Lepidosperma gladiatum* and *Juncus kraussii* closed rushland understorey. Along the southern section of the Peninsula, the dominant landform is parabolic dune-fields, and the peripheral vegetation to the seepage sites is *Juncus kraussii* closed rushland with no overstorey. The slightly undulating landform in the north provides a gentler gradient between the seepage areas and the surrounding terrain yielding a greater areal extent of the wet zone and a mixture of species present at the seepage points. In the south, the distinct interface between the wet zone and the parabolic dunes does not favour a mixing of the vegetation between the habitats.

Salinity of seepage sites

The salinity of the open Inlet water is generally 35 000 ppm, and the groundwater of the tidal flats is generally in excess of 50 000 ppm. Groundwater salinity within upper tidal flat or mid tidal flat settings in the range < 1 000 ppm, up to 6 000 ppm is strong evidence for freshwater dilution of the generally saline estuarine environment, and hence evidence for freshwater discharge.

At the 28 potential seepage sites on the first field visit in September 1986, water was collected from 34 sampling points for determination of salinity. Where the area of wetness at the site was extensive, two or more samples were collected. Further samples were taken later in the summer (November 1986) where standing water remained. Where two samples were taken at different times from the same sampling point the average of the two readings was used to characterise the sampling point.

The sites were then assigned into salinity classes according to Hammer (1986) as follows: Less than 1 000 mgL^{-1} = fresh; 1 000–3 000 mgL^{-1} = subhaline; 3 000–20 000 mgL^{-1} = hyposaline; and 20 000–50 000 mgL^{-1} = mesohaline.

Using this classification, of the 34 sampling points only one was fresh, seven were subhaline, twenty-four were hyposaline and two were mesohaline. At all times, the salinity of the open estuarine waters was near seawater. The average salinity for each site was calculated as the mean of all samples taken at that site, which is presented in Table 2 (multiple sampling).

The salinity data show that the seepage sites have fresh to brackish groundwater or surface water, and where transects have been established, the salinity changes up-slope from saline estuarine and tidal flat groundwater to freshwater at the point of freshwater seepage. Due to mixing with the surrounding saline environment it would not be expected that salinity readings would remain below 1 000 mg L^{-1} at seepage sites. Therefore, a threshold of 3000 mg L^{-1} is adopted here to identify freshwater seepage. Along the dune barrier, there are six sites with average salinities below 3,000 mg L^{-1} identified as significant freshwater seepage sites.

Table 2. Total dissolved solids measured at sampling site transects 1, 2, 3, 4 and 8 with description of location and surrounding vegetation (see Fig 1 for site locations). A, B, C, D refers to multiple sampling along transect from inlet edge to landwards.

Site	Total Dissolved Solids (‰) 8.9.86	14.11.86	Location	Vegetation
1(A)	ns	35	Inlet water	
1(B)	ns	3.84	Beach seepage 1 m from inlet	*Cynodon dactylon* closed herbland
1(C)	8.4	2.6	Small open pool 5-10 m from inlet	*Juncus kraussii* closed rushland
1(D)	1.8	0.63	Sedgeland 50 m from inlet	*Juncus kraussii/ Baumea articulata* closed sedgeland.
2(A)	ns	36	"Billabong" 1 m from inlet	*Sarcocornia quinqueflora* closed herbland
2(B)	ns	9.2	Small open pool 50 m from inlet	*Juncus kraussii* closed rushland
3(A)		35	Inlet water	
3(B)	12.6	ns	Small open pool 10 m from inlet	*Sarcocornia quinqueflora* closed herbland
3(C)	4.6	8.3	Sedgeland 20 m from inlet	*Juncus kraussii/ Typha orientalis* closed sedgeland
4(A)	16.5	ns	Small open pool 10 m from inlet	*Typha orientalis* closed sedgeland
4(B)	10.6	ns	Rushland 100 m from inlet	*Juncus kraussii* closed rushland
8(A)		35	Inlet water	
8(B)	2.25	3.33	Open rushland 5 m from inlet, east	*Juncus kraussii* open rushland side of road
8(C)	0.99	1.53	Small open pool, 15 m from inlet, west side of road	*Juncus kraussii* closed rushland

ns = not sampled.

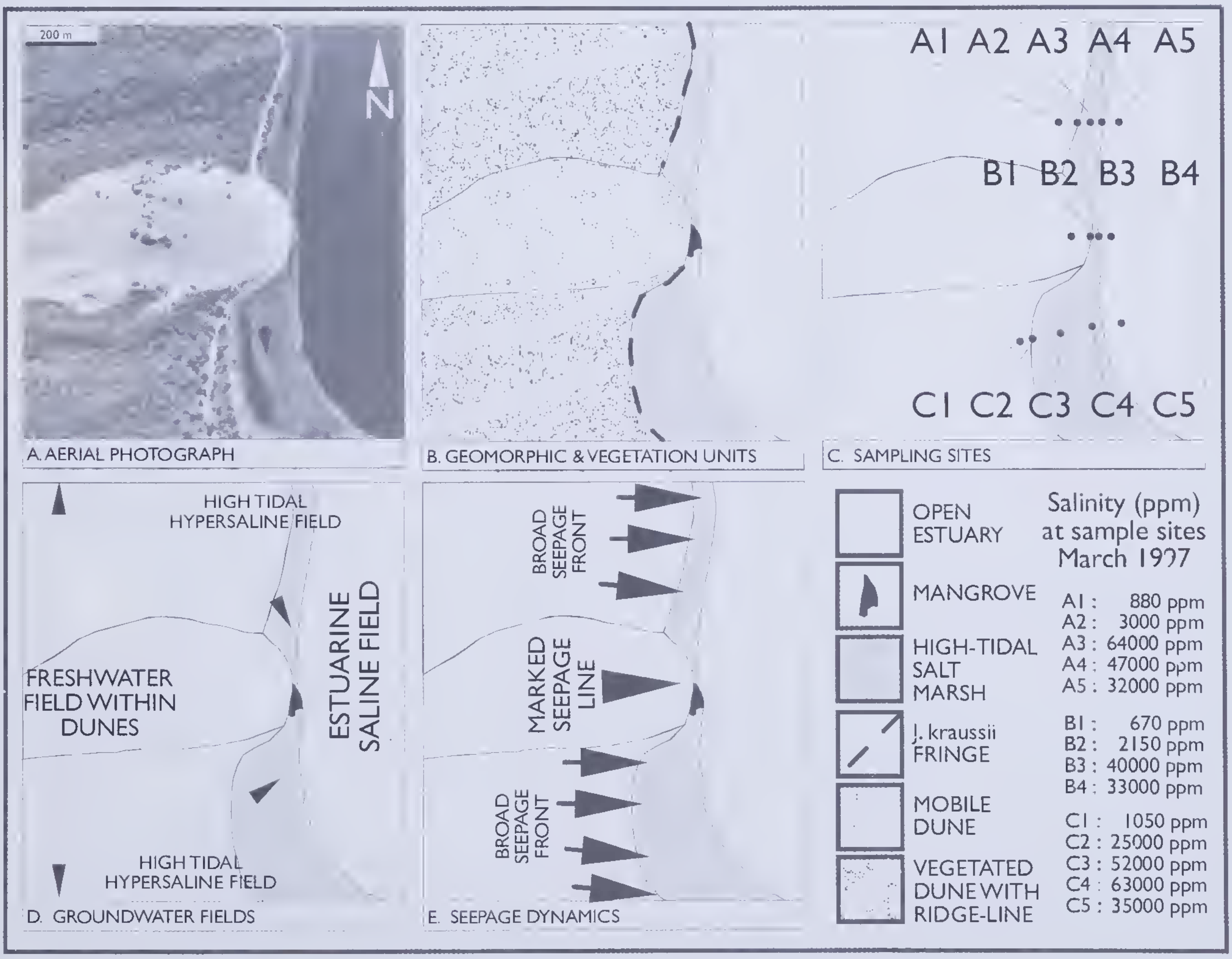

Figure 3. Maps showing terrain, study sites, seepage sites, and salinity values of sampling sites around the dune projection of Site 21 in March 1997.

Ten sites had average salinities between 3 000 and 6 000 mg L^{-1}, which may reflect minor seepage points having a diluting effect on the estuarine waters (Fig 4).

Site 21 is one of the best locations to study salinity changes induced by freshwater seepage into a saline groundwater environment (Fig 3). Here, a finger of dune sand is encroaching onto the high-tidal flat of the estuary. Fresh groundwater residing in the dune sand body forms an intrusive freshwater projection into the tidal flat. There

Table 3. Total dissolved solids measured at single sampling sites, with description of location and surrounding vegetation (see Fig 1 for site location)

	Total Dissolved Solids (‰)			
Site	**8.9.86**	**14.11.86**	**Location**	**Vegetation**
5	6.75	0.8	Rushland 100 m from inlet	*Juncus kraussii* closed rushland
6	1.35	1.44	Sedgeland 100 m from inlet	*Juncus kraussii/ Typha orientalis* closed sedgeland
7	17.1	ns	Small open pool 5 m from inlet	*Juncus kraussii* closed rushland
9	33	2.25	Small open pool, 20 m from inlet, west side of road	*Juncus kraussii* open rushland
10	3.8	ns	Small open pool, 5 m from inlet, east side of road	*Juncus kraussii* open rushland
11	14.7	ns	Small open pool, 10 m from inlet, east side of road	*Juncus kraussii* closed rushland
12	2.0	4.5	Small open pool, 30 m from inlet, west side of road	*Eucalyptus gomphocephala* open woodland
13	17	ns	Open water in closed rushland, 20 m from inlet, east side of road	*Juncus kraussii* closed rushland
14	3.3	2.6	Small open pool, 10 m from inlet (opposite .. line)	*Eucalyptus gomphocephala* open forest
15	2.5	3.87	Small open pool, 20 m from inlet	*Juncus kraussii* closed rushland
16	20	ns	Small open pool, 3 m from inlet	*Juncus kraussii* closed rushland
17	3.2	ns	Small open pool, 10 m from inlet	*Juncus kraussii* closed rushland
18	4.9	ns	Small open pool, 40 m from inlet	*Eucalyptus gomphocephala* open forest with *Lepidosperma gladiatum*
19	4.9	ns	Small open pool, 45 m from inlet	*Eucalyptus gomphocephala* open forest with *Lepidosperma gladiatum*
20	1.6	1.53	Small drainage rut, 20 m from inlet, west side of road	*Juncus kraussii* closed rushland
21	0.4	ns	Open water, 4 m from inlet	*Avicennia marina* closed scrub.
22	19	ns	Small open pool, 25 m from inlet	*Juncus kraussii* closed rushland / *Sarcocornia quinqueflora* closed herbland
23	4	ns	Small open pool, 100 m from inlet, 10 m east of road	*Melaleuca rhaphiophylla* low open forest / *Juncus kraussii* closed rushland
24	10.5	ns	Small open pool, 100 m from inlet, east side of road	*Melaleuca rhaphiophylla* low open forest
25	1.5	ns	Small open pool, 80 m from inlet, east side of road	*Melaleuca rhaphiophylla* low open forest
26	4.5	ns	Small open pool, 80 m from inlet, east side of road	*Melaleuca rhaphiophylla* low open forest
27	3.2	ns	Small open pool, 80 m from inlet, east side of road	*Eucalyptus gomphocephala* open forest / *Juncus kraussii* - *Lepidosperma gladiatum* open sedgeland
28	30	ns	Small open pool, 100 m from inlet, east side of road	*Eucalyptus gomphocephala* open forest

ns = not sampled.

is a steep hydraulic gradient between the fresh groundwater under the dune and the tidal flat, with brackish water in the zone of mixing along discharge/seepage zone.

Vegetation

The saltmarsh and halophytic vegetation associated with the seepage sites are (Tables 2 & 3):

- the fringe of *Juncus kraussii* along the interface between the dunes and the saltmarsh;
- forests of *Melaleuca rhaphiophylla* along the upper part of the high-tidal shore;
- scrub of mangrove *Avicennia marina* at the tip of a dune advancing into the estuary;
- mosaics and fringes of *Lepidosperma gladiatum*; and
- occurrences of *Eucalyptus gomphocephala* along the shore in interdune areas.

Occurrences of these vegetation types at the various sites, together with the salinity of the groundwater and any surface water at the seepage site are described in Tables 2 & 3.

Avifauna

During the surveys, white-faced herons (*Ardea novaehollandiae*) and Australian shelduck (*Tadorna tadornoides*) were sighted consistently in the vicinity of the freshwater seeps. There also were large mixed groups of waders, cormorants, gulls and pelicans near several different seepage sites during both visits, including marsh sandpiper (*Tringa stagnatilis*), greenshank (*Tringa nebularia*), red-necked stint (*Calidris ruficollis*), Australian pelican (*Pelecanus conspicillatus*), crested tern (*Sterna bergii*), silver gull (*Larus novaehollandiae*), and great egret (*Egretta alba*).

During the first survey, however, conditions were windy and it was assumed that birds aggregated near seepage sites more for shelter from the wind, than for usage of freshwater. Also, heavy rainfall prior to the first field survey had resulted in freshwater being freely available over much of the low-lying terrain. Consequently, birds were widely dispersed over much of the area, and there was no need for birds to remain near seepage sites. The field survey thus showed no exclusive use of seepage areas by large numbers of birds. On the second field survey, high barometric pressure and low tide resulted in very low water level in the Inlet. Consequently, with the exposure of previously unavailable mudflats, most birds were away from the near-shore and feeding on the mudflats. Strong winds also affected bird behaviour with many species absent from the Inlet and near-shore, while many others found to be sheltering in the embayments. From this perspective, the information on avifauna collected during the two survey periods in relation to their use of freshwater seepage zones overall was inconclusive.

However, there were occurrences of single white-faced herons on ten of the small open pools associated with freshwater seepage, demonstrating some use of freshwater-influenced resources. Other white-faced herons were noted

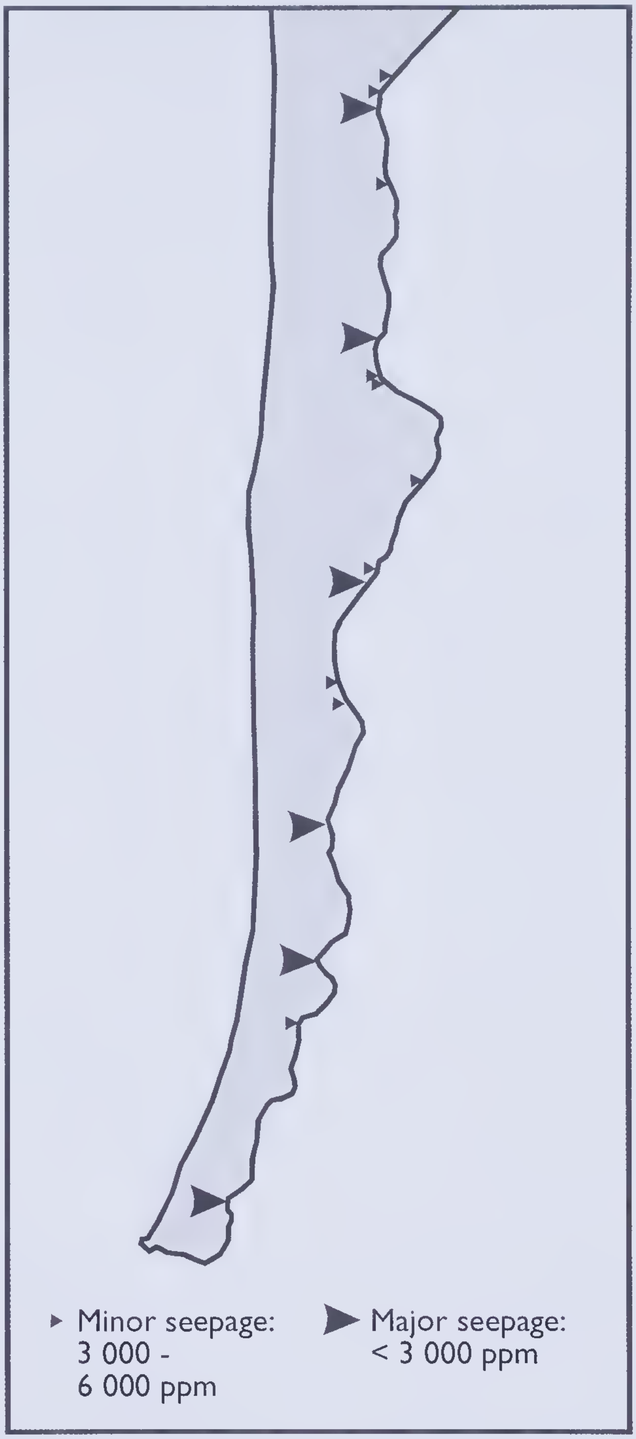

Figure 4. Map showing location of major and minor seepage sites.

feeding in the estuary and saltmarshes. This species appeared to favour the sedgelands surrounding the small pools, presumably for protective cover, while feeding took place over the entire range of shallow waters in their immediate vicinity. Additionally, two breeding pairs of Australian shelduck were observed close to freshwater seepage points during September/October. Australian shelduck require freshwater bodies or estuaries and saline water bodies adjacent to freshwater sources, with nesting taking place in hollow trees, on the ground, in sandbanks, and holes in limestone (Johnstone & Storr 1998). The presence of breeding pairs would indicate the reliability of the freshwater seepages.

Discussion

The combination of several environmental indicators within a landscape ecological approach provides a useful framework for understanding the natural processes operating at the landscape scale. In this context, the study of the landform, vegetation, water quality and avifauna use in a combined survey can provide appropriate information to conclude that the freshwater seepage points along the Inlet are important in maintaining landscape heterogeneity and attendant biodiversity.

In regard to saltmarsh vegetation, Cresswell & Bridgewater (1998) note that for many of the saltmarsh assemblages a large number of constituent ephemeral species tend to occur in winter-wet depressions in the marsh. This increases patch heterogeneity in the saltmarsh and thereby enhances the range and availability of the food resources. This would be a direct consequence of freshwater seepage effects. Cresswell & Bridgewater (1998) also discuss the occurrence of alien species in one of the more common saltmarsh assemblages of the Leschenault Inlet mudflats, and conclude that, generally, indirect human influence through environmental change is the main cause of the colonisation and proliferation of alien species in saltmarshes.

In many of the other major occurrences of similar saltmarsh systems in the estuarine systems in this region, there has been an increase in the abundance of alien species, probably due to the extensive disturbance suffered by these marshes from grazing and associated clearance. Associations in areas of dense human settlement tend to have greater numbers of alien species as constituents, with greater population numbers. The high quality of the saltmarshes of the Leschenault Inlet can be attributed to the remoteness from intensive human activity, which further enhances the quality of the marshes as a resource for the avifauna.

In relation to avifauna, the natural setting of the Leschenault Peninsula and Inlet provides important resources for many species of permanent and migratory waterfowl. The Peninsula itself provides protection from the strong westerly/south westerly winds, as well as providing a freshwater catchment and groundwater reservoir, which then seeps into the inlet well after the rains have ceased. This would be important for the many species of waterfowl having a daily requirement for fresh water whilst mainly feeding in the saline estuary. The length of the Peninsula is also important in that it provides a large area of differing habitats along its estuarine shore. Bird usage of the entire area, however, is extremely complex and would require much more intensive work to determine patterns in relationship to topography, feeding grounds, freshwater seepage, amongst others.

The shallow waters of the Inlet and associated mudflats during low tide provide feeding areas for avifauna, particularly given the extensive area and range of shallow water which provide a great variety of food sources. The shallowness of the Inlet also has restricted many forms of human recreation and commercial activity that would otherwise severely disturb waterfowl. Many species that are rarely seen in the region are present at different times of the year, such as the yellow-billed spoonbill (*Platalea flavipes*), a recent colonist to south-western Australia.

Importantly, the remoteness from human settlement and activity provides eremitic species with habitats that exist in few other places along this coastal sector due to increasing human settlement. The lack of major human disturbance to the environment of the Peninsula has been fundamental in maintaining the high ecosystem quality of the area.

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